

Review Article

Characterization of Novel Edible Films and Coatings for Food Preservation Based on Gum *Cordia*

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As a pharmaceutical component, gum *Cordia* has been applied to improve crop resistance against many diseases. A large amount of gum appears around the fruit after soaking in an aqueous system. The mucilage possesses outstanding technofunctional properties as an emulsifier, thickening agent, and binding and stabilizing component in food and drug industries. The backbone of gum *Cordia* is composed of (1-2)-linked L-arabinofuranosyl and (1-6)-linked D-glucopyranosyl residues. This manuscript reviews the technofunctional properties and applications of gum *Cordia* in food systems. Particularly, our focus has been given to its application as a natural source for the formation of edible films and coatings for increasing the shelf life of food products and for the food preservation as a potential ingredient in formulation. The future research perspectives are also highlighted.

1. Introduction

Nonbiodegradable and synthetic polymeric substances are vastly used as food packaging materials that have caused significant environment concerns all over the world. Possible alternatives for plastic packaging materials are those obtained from natural and renewable resources such as polysaccharide- and protein-based films and coatings [1–4]. These films and coatings have no effect on the manufacturing process of food or its ingredients and can be readily applied as thin biopolymer layers through a wrapping or submerging process. Biopolymer-based films and coatings can be loaded with natural antioxidants and antimicrobials and other bioactive components and flavors. They are also edible, available, and biodegradable which make them a better option in comparison with synthetic materials [5, 6].

In contrast to synthetic and semisynthetic polymers, fruit polysaccharides are for sure vastly available, cheap in processing costs, nontoxic, biodegradable, and not

dangerous to the environment, and these features make them to be applied more rather than the synthetic agrochemicals [7]. Consequently, one of the less utilized and remarkable fruits, *Cordia* with different species, could be a novel and potential plant source of hydrocolloids. Noteworthy, physicochemical properties of natural polymers have made them adorable and applicable for different applications in pharmaceutical and food industries [8]. *Cordia* is a flowering plant genus from the Boraginaceae family. This genus with almost 250 species generally grows in warm regions. *C. latifolia*, *C. myxa*, *C. dichotoma*, and *C. abyssinia* are the four species of *Cordia* which are considered advantageous for a number of applications in different scientific articles [9]. *Cordia* is found in tropical and subtropical zones of Africa, America, Oceania, and Asia [10]. The structure of gum *Cordia* is formed from the backbone of (1-2)-linked L-arabinofuranosyl and (1-6)-linked D-glucopyranosyl residues inside arabinoglucan formation [10]. Gum *Cordia* affects health positively as it has valuable nutritional compounds. Some healing aspects of gum *Cordia*

TABLE 1: Constitution contents and pH amounts related to gum *Cordia*.

Chemical composition content (%)							
Moisture	9.26 [10]	9.10 [15]	9.1 [16]	8.34 [17]	6.90 [7]		
Protein	2.47 [10]	2.60 [15]	2.6 [16]	12.75 [17]	8.90 [7]		
Total carbohydrate	78.22 [10]				77.51 [7]		
Fat					1.00 [7]		
Ash	1.75 [10]	0.70 [15]	6.58 [12]	0.7 [16]	0.98 [17]	1.47 [18]	5.86 [7]
Soluble sugar							
Uronic acid		8.7 [15]		8.7 [16]	10.22 [17]		
pH and yield							
pH		6.5 [12]				7.2 [18]	
Yield (%)			1.2 [16]	1.56 [17]			
Mineral ion content (ppm)							
Calcium						8700 [7]	
Phosphorus						700.21 [7]	
Potassium						4.40 [7]	
Zinc						186.11 [7]	
Iron						120.97 [7]	

involve anti-inflammatory, astringent, antimalarial, diuretic, febrifuge, anthelmintic, cicatrizant, cough suppressant, and appetite suppressant properties and is capable of curing lung diseases, leprosy, and urinary infections. Moreover, some studies show other applications of gum *Cordia* such as the sustained-release matrix in the bead, nanoparticles, tablets, and microcapsules, and also utilization as an emulsifier and binder [11, 12].

This manuscript reviews the technofunctional features of gum *Cordia* in food systems. However, the main focus has been given to its application as a natural polymer for the formation of edible films and coatings to increase the shelf life of food products.

2. Gum *Cordia*

2.1. Chemical Constitution. Purity is probably the first item for identifying the properties of gums. Normally, gum *Cordia* includes 77–78% carbohydrate, 2.6–12.75% protein, 6.90–9.26% moisture, 0.7–5.86% total ash, and 0–1% fat (Table 1). Carbohydrate is obviously the most abundant constituent in gum *Cordia*. It is more than the reported amount for gum ghatti (78.36%) and guar gum (71.1%) and close to the amount in the locust bean gum (85.1–88.7%) [13, 14]. The subtraction of other component contents of the gum from 100 equals 77.51% carbohydrate which is to a slight extent less than the total carbohydrate content acquired by the phenol sulfuric acid assay which equals 84.32%. Insufficient ashing (550°C and 3 h) might be the reason for this distinction. This amount of carbohydrate shows the high purity of gum *Cordia*. In addition, besides its purity, this gum has a good extraction efficiency that makes it a possible candidate for replacement of some commercial gums [7].

Functional properties such as stabilizing, emulsifying, and film-forming abilities could be due to the protein content inside the gum [19]. The protein fraction of gum *Cordia* was similar to that of the guar gum (8.19%) and higher than that of the locust bean gum (5.2–7.4%) and xanthan (2.125%) [20]. Although more studies are needed, it

can be considered that this gum is an emulsifier and can decrease surface tension since it has a high level of protein. The percentage of ash in gum *Cordia* was considerably less than that of the guar gum (11.9%) and close to that of the xanthan gum (1.5%), locust bean gum (0.7–1.5%), and gum Arabic (1.2%) [20]. It is indicated by the obtained results that the water soluble part of ash inside gum involves 3.64% of the whole ash amount which is 5.86% [7].

Methyl esterification of some uronic acid groups of gum *Cordia* was carried out in both ethanol and acid precipitation to 38% methoxyl content [16]. Functional features of the polysaccharide, including formation of gel, are probably affected by methoxyl groups due to the investigation of low and high methoxy pectins [21]. No starch was observed as no sample turned blue during the iodine test. This polysaccharide was almost insoluble in organic solvents and soluble in hot water with the appearance of a colloidal solution. It also had near-neutral pH in the form of 1% (w/w) solution [18]. Additionally, the solution of gum *Cordia* has the pH of around neutral as well. That possibly means no irritative impact to the mucous membrane and epithelium is expected from gum *Cordia* in the gastrointestinal tract [22].

The mineral compounds in hydrocolloids have an impact on functional and physicochemical behaviors. For instance, the trace amount of iron (Fe) is destructive to the emulsifying ability of hydrocolloids [23]. Furthermore, gel-forming capacity and rheological properties of polyelectrolyte hydrocolloids can be influenced by the calcium ion (Ca^{2+}) [24]. Cadmium and some other ions with significant concentrations can cause health problems. Gum *Cordia* consists of 19700 ppm potassium, 8700 ppm calcium, 700 ppm phosphorus, 186 ppm zinc, and 120.97 ppm iron, but Ca and Cu concentrations did not reach the method detection limits (MDL). Table 1 shows the measured amounts of minerals. It can be found from these results that gum *Cordia* is rich in potassium (19700 ppm), calcium (8700 ppm), and zinc (185.93 ppm) though its copper and cadmium amounts are negligible. Gum *Cordia* has more valuable nutritional compounds than other commercial gums, such as guar, gum Arabic, and xanthan [25].

TABLE 2: Ratio of sugar composition in gum *Cordia*.

	Haq et al. [9]	Benhura and chidewe [15]
Arabinose	11	9
Galactose	31	27
Glucose	18	10
Mannose	11	17
Rhamnose	17t	21
Uronic acid	6	5
Xylose	6	11

Therefore, in pharmaceutical and food science fields, gum *Cordia* could certainly be known as a value-added byproduct.

2.2. Carbohydrate Analysis. HPLC method was used to study sugar hydrolysates from gum *Cordia*. Arabinose, galactose, glucose, mannose, rhamnose, uronic acids, and xylose were traced, and in two different studies, respectively, 11:31:18:11:17:6:6 [9] and 9:27:10:17:21:5:11 [15] ratios were obtained. Table 2 displays the results of these analyses. As a result of inadequate digestion, it was impossible to report the absolute mass basis of hydrolysates. The data from these two studies cannot be concluded, as digestion was insufficient, and they were unlike the mentioned ratios of *C. abyssinica*.

2.3. Molecular Information. Functional properties of gum are remarkably affected by its molecular weight [26]. In gel permeation chromatography (GPC), gum *Cordia* presented a major peak, after which two small peaks appeared. Consequently, it is estimated that the formation of gum *Cordia* consists of three parts with different molecular weights. Haq et al. [9] observed two peaks related to gum by the GPC method, showing the average molar mass of 1.81×10^6 and $3.89 \times 10^3 \text{ g}\cdot\text{mol}^{-1}$. Usually, the average molar mass of the first fraction in gums with a plant base is about $10^5 \text{ g}\cdot\text{mol}^{-1}$, which is almost lower than the amount for gum *Cordia*. Gum *Cordia* has the average molecular weight of $2.23 \times 10^4 \text{ g}\cdot\text{mol}^{-1}$ [7] that is lower than plenty of commercialized gums such as xanthan with $4.05 \times 10^6 \text{ g}\cdot\text{mol}^{-1}$ [27], gellan gum with $1.64 \times 10^6 \text{ g}\cdot\text{mol}^{-1}$ [28], and guar gum with $1.45 \times 10^6 \text{ g}\cdot\text{mol}^{-1}$ [29]. The number average molecular weight (Mn) of gum *Cordia* was estimated as $1.34 \times 10^4 \text{ g}\cdot\text{mol}^{-1}$. A molecular factor for understanding the molecular weight distribution and homogeneity of biopolymers is the polydispersity index ($\text{PDI} = \text{Mw}/\text{Mn}$), which often ranges from 1.16 to 2.86 in natural polymers. Gum *Cordia*, with a value of 1.66 [7], had a lower PDI than lots of hydrocolloids since more uniformity was found in the gum, and on the contrary, was near to that of gum Arabic with 1.2652 and guar gum with 1.21 [30]. Unlike other gums with a plant base, such as gum Arabic ($\text{PDI} = 2.27$) and kappa-carrageenan ($\text{PDI} = 3$), both mentioned fractions of gum *Cordia* had PDI of around a uniform condition value [9]. PDI expresses the heterogeneity inside chains of the polymer. Molecular mass distribution of gum *Cordia* is very limited, so the PDI value is about 1. This is a desirable trait of

gum that makes it favorable to be used in edible films since better tensile strength occurs in chains with homogenous structures.

2.4. Fourier-Transform Infrared Spectroscopy (FTIR). Analysis of gum *Cordia* by FTIR spectrometry was carried out for recognizing its functional groups. As a matter of fact, all of the usual peaks and bands related to polysaccharides can be seen in the gum spectrum [7]. At 848.2 cm^{-1} , a noticeable shoulder represents the linkage of alpha and beta in the structure of gum [23]. Finger print area (from 1000 to 1200 cm^{-1}) is a region in which any polysaccharide shows a particular behavior. This area explains the distinctions in structures of biopolymers. The signal at 1030 cm^{-1} is related to uronic acid. There are some peaks in the range of 950 to 1200 cm^{-1} as a result of the stretching vibration associated with alcoholic CO in COH bands inside carbohydrates [22]. The observed peak at 1635 cm^{-1} shows valence vibration and carboxyl groups. Gel-forming ability and viscosity could be affected by possible interactions between some ions, such as calcium and carboxyl groups [31]. Carboxylic ester causes the wavenumber near 1737 cm^{-1} . The small peak at 2921.91 cm^{-1} expresses the stretching vibration of C-H related to the methylene group. Double overlapping with hydroxyl groups might cause this peak as well. The peak at 3438.81 cm^{-1} is related to the stretching vibration of O-H. Hydrogen bonding of the hydroxyl groups inside glucopyranose rings is also associated with this enormous peak [32].

2.5. Differential Scanning Calorimetry (DSC). Differential scanning calorimetry (DSC) uses temperature for tracking the obtained or lost heat in samples, during chemical and physical changes. Impurities are explained by wide asymmetric curves which could also be the sign of two or more thermal processes, and relative purity is described by an obvious symmetric peak of the melting endotherm [18]. Phase transitions in polymers are commonly investigated by DSC since it is a very precise and sensitive method. Occurrence of changes in the main chain during heating causes two endothermic behaviors in the DSC thermogram of gum *Cordia*. The first endothermic reaction of gum *Cordia* happened as a result of bound and free water loss, and a vast peak appeared around 147°C which is the glass transition temperature (T_g). Decomposition or melting of gum at 238°C (melting temperature or T_m) brings up the second endothermic reaction and provokes a little peak at the related temperature. It can be found that although gum *Cordia* looks crystalline, it has an amorphous characteristic, considering its wide DSC thermogram. In the industry (production and storage stages), it is important to have information about the glass transition temperature and the items that have impact on it, such as additives and moisture that change the formation of molecules and consequently simplify the transformation to the crystalline or rubbery phase [32]. In different studies, low crystallinity was observed for substances with a low glass transition temperature [22].

2.6. X-Ray Diffraction (XRD). Remarkable peaks of gum *Cordia* appear of the order of 2θ which equals 26° , 29° , 30° , and 5° . Meanwhile, uncertain and very small peaks and also shoulder forms stuck to other strong peaks can be seen. XRD data estimate the occurrence of both crystalline and amorphous forms in gum *Cordia*, which confirms the results of DSC [18].

3. Applications

3.1. Biodegradable Edible Films. The quick increase in the production rate of nondegradable petroleum-based plastic materials causes serious environmental concerns [33]. Therefore, many efforts have been made to find environmentally friendly materials. Natural polymers (proteins and polysaccharides) have received much attention due to biodegradability [17]. One of the important applications of gum *Cordia* is the production of edible films. Haq et al. [34] studied the properties of the edible gum *Cordia* film with added beeswax. Beeswax affected the film by decreasing its elongation at break, tensile strength, and Young's modulus. Gum *Cordia* films with beeswax had a water vapor permeability of $0.06\text{--}0.33 \times 10^{-10} \text{ g}\cdot\text{m}^{-1}\cdot\text{s}^{-1}\cdot\text{Pa}^{-1}$, which is lower than that of the control films. Additionally, it is found that oxygen permeability becomes greater from 0.39 to $18.73 \text{ g}\cdot\text{m}^{-1}\cdot\text{s}^{-1}\cdot\text{Pa}^{-1}$ in a beeswax concentration of $0.05 \text{ g}\cdot\text{g}^{-1}$. Nevertheless, oxygen permeability stopped increasing as beeswax reached higher concentrations. Results obtained from this work will draw attentions to *Cordia* as a plentiful source of gum and ease its applications. Further progression is also expected in edible packaging made from gum *Cordia*, for fresh material coating, specifically. Haq et al. [35] analyzed the attributes of the edible gum *Cordia* film affected by plasticizers. Edible gum *Cordia* films were made considering the concentration and kind of the plasticizer and then their permeability to gas, and also their rheological and thermal characteristics were studied. The solution casting method was carried out for production of the films. Chosen plasticizers were PEG (polyethylene glycol) 200, PEG 400, sorbitol, and glycerol for an amount of 0.1 to $0.3 \text{ g}\cdot\text{g}^{-1}$ dry polymer weight basis. It was indicated that film behaviors rely on the concentration and nature of the plasticizer. Gum and plasticizers had interactions which were recognized by FTIR spectroscopy. Miscibility of gum and plasticizers was estimated by DSC. The glass transition temperature was observed inside the range of -66 to -11°C . From the rheological point of view, these films had elongation at break of more than 10% and tensile strength of higher than 10 MPa. Glycerol, sorbitol, PEG 200, and PEG 400 caused the most remarkable tensile changes, respectively. Water vapor permeability was measured from 0.91 to $5.5 \times 10^{-10} \text{ g}\cdot\text{m}^{-1}\cdot\text{s}^{-1}\cdot\text{Pa}^{-1}$. Oxygen permeability was obtained in range of 0.16 to $5.31 \times 10^{-15} \text{ g}\cdot\text{m}^{-1}\cdot\text{s}^{-1}\cdot\text{Pa}^{-1}$. Edible film could be prepared by the casting method from gum *Cordia* added with various plasticizers. Modification of these films is possible by using different plasticizers and their various concentrations. Miscibility and interactions between plasticizers and gum were observed in the produced films. Addition of glycerol, sorbitol, PEG 200, and PEG 400 to gum

Cordia films, respectively, was responsible for higher induced elongation at break and tensile strength. Adding PEG 400 can also hold the oxygen permeability in a lower amount. This research announces *Cordia* as a plant with simple uses in the mentioned area and gives hope for improvement of edible packaging. Haq et al. [36] reported that plasticizers have an impact on optical and sorption characteristics of edible gum *Cordia* films. The goal was to identify the biodegradable film made from the extracted gum of plant *Cordia*. PEG200, PEG 400, sorbitol, and glycerol were used as plasticizers with concentrations of 0 to 30% to investigate their influence on optical and sorption behaviors of the casted film. The results of this analysis corresponded to the type II isotherm, according to the GAB model of sorption since the equilibrium moisture content of films increased by increasing the concentration of plasticizers. Increasing the concentration of the plasticizer also increased the value of the monolayer, as the most effective one was glycerol with $0.93 \text{ g}\cdot\text{g}^{-1}$. Total color difference (ΔE) was enhanced as more plasticizers were added, and glycerol had the most impact again. All samples resisted 200 to 280 nm wavelength of UV spectra. A comparative film with more desirable characteristics for edible coating applications could be made from *Cordia myxa* fruit gum. Plasticizers along with anionic *Cordia* gum create the film. In comparison with typically used edible films, this one involved more preferable optical properties and sorption isotherms. Each plasticizer was tested in terms of its concentration to indicate its efficacy, and it became clear that glycerol was the most effective. By applying the GAB equation, sigmoidal curves of isotherms related to gum *Cordia* films could be drawn. Water molecules bond to sorption sites of gum by a lower rate since plasticizers reduce the needed energy for this action. The total color of the gum *Cordia* film was also lowered by presence of plasticizers. Incorporation of gum *Cordia* with every plasticizer produced transparent films. But, the UV spectrum could not pass through these films easily.

3.2. Coating Applications. Application of gum *Cordia* as a coating especially for nuts was reported in various research studies. El-Mogy et al. [37] investigated the impact of gum *Cordia* on the postharvest quality of fresh artichoke bottoms. Results showed that the addition of ascorbic acid or CaCl_2 to gum *Cordia*-based edible coatings improves the amount of total phenolic compounds and vitamin C and prevents the weight loss. Gum *Cordia* incorporated with ascorbic acid considerably inhibited polyphenol oxidase and browning activities. Gum *Cordia*-free CaCl_2 solution reduced the count of psychrotrophic and mesophilic bacteria. The strongest treatment against *E. coli* and molds was the combination of CaCl_2 and gum *Cordia*. Therefore, a mixture of gum *Cordia* and CaCl_2 was suggested as a proper coating for artichoke bottoms during postharvest storage. More research studies are needed for the commercial application of gum *Cordia* in preserving fresh-cut artichoke bottoms. Haq et al. [38] studied potentials of gum *Cordia* to prevent oxidation of lipids in peanuts as an antioxidant carrier.

Attachment to the polymer matrix (e.g., edible films with a gum base) enhances the efficiency of antioxidants. Good emulsification and adhesion capabilities of gum *Cordia* make it a possible carrier for antioxidants. The purpose of this investigation was to inspect the capacities of gum *Cordia* for coating peanuts in the form of an antioxidant carrier. Antioxidants for delivery action included vitamin C, BHA (butylated hydroxyanisole), and BHT (butylated hydroxytoluene) used in a comparison between gum *Cordia* and carboxymethyl cellulose as carriers. Carrier efficiency of two gums was compared by analyzing the oxidized flavor, thiobarbituric acid-reactive species, and peroxide value of uncoated and coated peanuts which were kept at 35°C for 126 days. Uncoated and coated peanuts showed significant differences ($p < 0.05$). Gum *Cordia* was a better carrier in antioxidant delivery. According to the peroxide value (40 meq of $O_2 kg^{-1}$), gum *Cordia* with BHA/BHT (290% more shelf life than the uncoated sample), gum *Cordia* with BHT (244%), gum *Cordia* with BHA (232%), carboxymethyl cellulose with BHA/BHT (184%), carboxymethyl cellulose with BHA (139%), carboxymethyl cellulose with BHT (119%), gum *Cordia* with vitamin C (96%), and carboxymethyl cellulose with vitamin C (46%) fulfilled carrier responsibility, respectively. Therefore, it is clear that gum *Cordia* acts as a capable carrier for antioxidants and probably other functional stuffs in the form of edible coating. Other conditions are being studied for more advances in using this gum as a coating film. Abdul Haq et al. [39] carried out assessments to improve the shelf life of *Pinus gerardiana* by gum *Cordia* edible coating. Anionic gum of *Cordia* is the reason for its good adhesion ability. *Pinus gerardiana* is full of unsaturated fatty acids which makes its unshelled nuts vulnerable to oxidation. Carboxymethyl cellulose and gum *Cordia* were compared in terms of preventing rancidity of *Pinus gerardiana* in the form of edible coatings. Carboxymethyl cellulose and gum *Cordia* each included a free sample and a sample containing natural antioxidants. Studied antioxidants were α -tocopherol and the methanolic extract of *Cordia myxa*. Sensory and chemical analyses were carried out on all samples (coated and uncoated) which were kept at 35°C for 112 days. Uncoated and coated nuts demonstrated significant differences ($p < 0.05$). In accordance with the peroxide value (20 meq of $O_2 kg^{-1}$), samples involving gum *Cordia* with the added extract of *Cordia myxa*, carboxymethyl cellulose with the added *Cordia myxa* extract (circa 60%), free gum *Cordia* (circa 25%), and free carboxymethyl cellulose (circa 15%) showed the most effectiveness, respectively. α -Tocopherol did not exhibit any impact on nuts. Consequently, gum *Cordia* could act as a potent natural edible film for inducing higher shelf life in pine nuts. This gum might also be an option in other foods for increasing shelf life and invincibility to rancidity by its coating capability. Haq and Hasnain [40] studied gum *Cordia* coating with involvement of antioxidants to prevent rancidity of peanuts. Abilities of two gums, i.e., gum *Cordia* and carboxymethyl cellulose, in improving shelf life of peanuts were compared. Samples of both free and with natural antioxidants of carboxymethyl cellulose and gum *Cordia* were investigated. α -Tocopherol and the methanolic

extract of the *Cordia myxa* fruit were the present antioxidants. Peanuts were held at 35°C for 126 days, and their sensory and chemical properties were analyzed. By considering the peroxide value (40 meq $O_2 kg^{-1}$), gum *Cordia* having the *Cordia myxa* extract showed 122%, free gum *Cordia* showed 91%, carboxymethyl cellulose having the *Cordia myxa* extract showed 80%, and free carboxymethyl cellulose showed 70% growth in shelf life of samples. No beneficial effect was induced by α -tocopherol. It is estimated that increasing shelf life of peanuts is possible by gum *Cordia* coating although no information exists about its mechanism of action. More studies are being done for a better understanding of the physicochemical attributes of edible gum *Cordia* coatings. Foods with a high lipid content could be the targets of this natural coating for increasing their shelf life.

4. Conclusion

This review article, which is based on the findings of the studies on gum *Cordia*, demonstrates that the gum *Cordia* may be used to improve the viscoelastic, textural, stability, and other parameters of foods and drugs. It can be applied to create novel applications such as encapsulation and delivery of bioactive ingredients. These beneficial properties suggest this gum as a proper component which could potentially be used for different purposes in pharmaceutical and food products. But, still more research is needed to find the chemical structure and other important technofunctional characterization of gum *Cordia*. This gum may be of technological importance and can be used for the improvement of food product quality.

More research works are required to be carried out in the field of modified processing methods and isolation and purification techniques. Structure-function relationship elucidation and backbone-directed chemical modification of gum *Cordia* might expand its applications in the food industry.

Data Availability

The data used to support the study are included within the article. Any more information can be obtained by contacting the corresponding author.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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